Determining a Secure Region of Operation for Idaho Power Company

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***Abstract*—This paper deals with quick security calculations that provide a quantitative impact of every contingency on system conditions in Idaho Power Co. while simulating two simultaneous power transfers. The secure region of power system operation is determined and plotted for each contingency. Contingencies are ranked based on the size of the secure operating region, and the most limiting contingencies are identified. Optimal mitigation measures that increase the size of the secure operating region are then determined for each contingency. The effect of remedial actions on the size of the secure operating region is analyzed. The study was performed using full AC analysis methodology for contingency screening and transfer studies. AC limits for transfer scenarios are computed based on thermal, voltage and voltage stability constraints.**

***Index Terms*—boundary of secure region of operation, simultaneous power transfers, contingency ranking, optimal mitigation measures.**

I. Introduction

HISTORICALLY, security and transfer capability calculations have always been of paramount importance to the safe and economic operation of power systems. Power system security problems have received even more attention recently due to widespread implementation of electricity markets, power industry restructuring and the major blackouts happened across North America and Europe. Today, more and more utilities across globe, in order to stay competitive in the open-competitive market, operate their systems with heavier flows on transmission lines and with lower security margins. This course has tendency to stay, so it has prompted an improvement of existing or development of new methodologies and tools to ensure secure operation, prevent wide spread disturbances and to increase further the utilization of the system.

Considerable published work over the last two decades has been devoted to the various aspects of security and transfer capability calculations in transmission power systems [1].

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Generally, the research in the area of security moves along two different directions. The first direction, represented by references [2-15] calculates security margins based on deterministic criteria. The second direction represented by references [16-22] deals with security aspects based on probabilistic criteria. At present most utilities use deterministic criteria defined by North Electric Reliability Council (NERC) that distinguish various categories of contingencies (N-0, N-1, N-2 and N-k) with respect to pre- and post-contingency conditions.

Despite the tremendous research and development efforts in the security assessment area, utilities still have needs for more solid and robust methodologies and tools to perform the necessary security tasks. The security assessment task from the implementation point of view can be divided into two basic problems. One is to assess the security of a given operating point and the second is to determine the boundary of the security region i.e. the security margin. This paper deals with deterministic criteria and specifically focuses on the second type of security problem. Operating within the boundary is secure. Each point on the boundary corresponds to at least one of the constraints being violated. The size of the security region, in general, is a nonlinear function of the system operating conditions and security constraints and depends on a number of factors such as system configuration, generation dispatch, load level, load distribution, power transfers between areas and the limits imposed on the transmission network due to thermal, voltage and stability considerations. The ability to know how much load can be met and how much power can be transferred from one point to another while maintaining a secure operation of the system is of great concern to a utility, so it was the main motivation for this paper.

Presented method determines boundary of the secure operating region using Boundary of Operating Region (BOR) for an actual external path in Idaho power system. It prescribed the operation guide how much this path can be stressed without running into violations of monitored security limits. Companion program Optimal Mitigation Measures (OPM) invokes remedial actions schemes (RAS) and post-contingency procedures as mechanisms to mitigate post-contingency security violations. It was shown that application of adequate remedial actions translate into resizing of the secure region in the way an operating point from outside is moved inside of this region. The results on the Idaho power system demonstrate the effectiveness of the newly developed method on finding boundary of the secure operating region.

The paper is organized as follows. In Section II, an Idaho's transmission path was studied. Section III shows the results of contingency analysis obtained using the proposed approach. Section IV is devoted to increasing the size of secure operating region. Detailed security assessment is given in Section V. Finally, in section VI, some conclusions are presented.

II. SIMULATING TWO SIMULTANEOUS POWER TRANSFERS

This section describes transfer simulation study that was performed for Idaho Power base case consisting of approximately 14000 buses and 17000 branches.

Power transfers are simulated by increasing the import to Idaho from Northwest.

Power transfers are simulated by increasing generation in the source area (Northwest) and decreasing generation in the sink area (Idaho Power Co.). Two subsystems are selected in the sink area: Hells Canyon generation and Bridger generation, see Fig. 1.

Two transfers are simulated:

- Transfer 1: From Northwest to Hells Canyon generation
- Transfer 2: From Northwest to Bridger generation

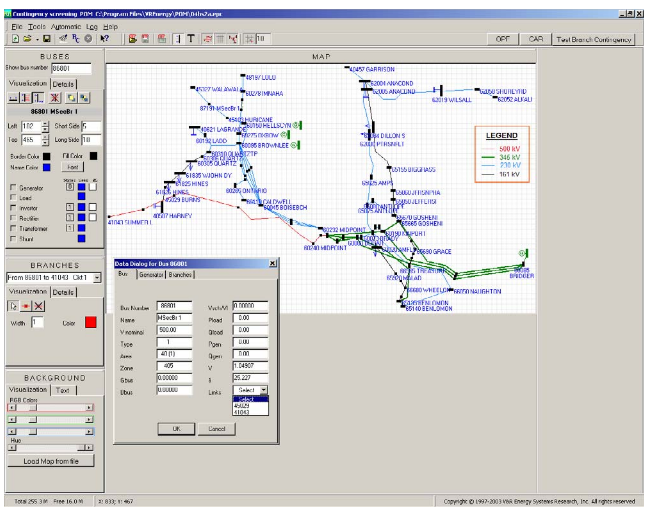

Fig. 1. Map of Idaho Power Co.

The following constraints are simultaneously monitored during power transfer analysis:

- Voltage stability constraint
- Thermal constraint

  115% of Rating B is monitored as the thermal constraint.
- Voltage constraint

  Pre-to post contingency voltage drop of 5% is monitored for N-1 contingencies.

  Pre-to post contingency voltage drop of 10% is monitored for N-2 and higher order contingencies.

Options for constraint monitoring were selected as shown in Fig. 2.

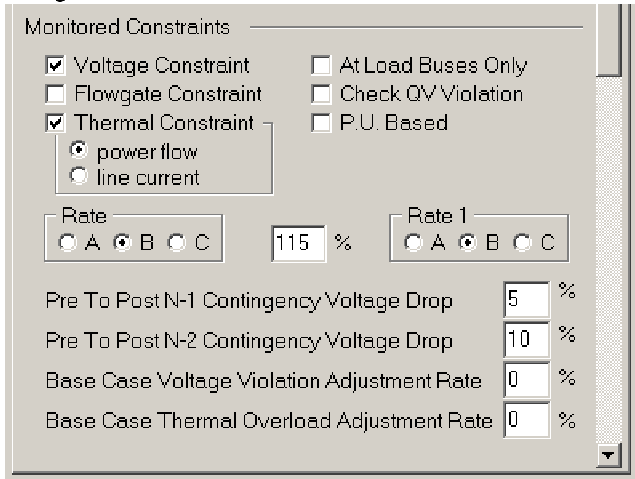

Fig. 2. Monitored Constraints Options

Two simultaneous power transfers are simulated.

Fig. 3 shows the boundary of the operating region for two simultaneous transfers for the base case conditions (i.e., no contingencies are applied).

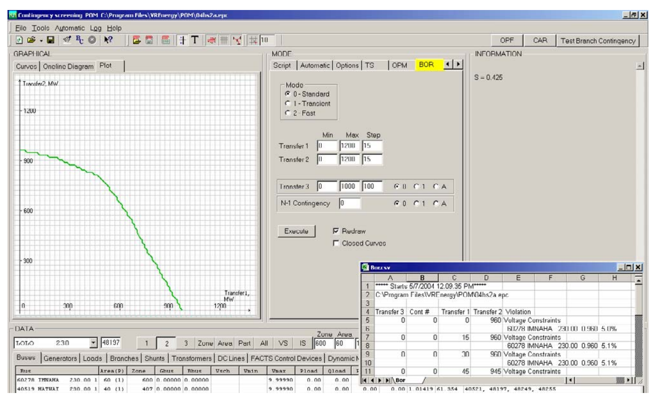

Fig. 3. Boundary of Operating Region for Two Simultaneous Transfers

The boundary is a multi-colored graph. Each color on a boundary corresponds to violation of one of the following constraints and limits that occur beyond the operating region:

- Pink - Thermal violation;
- Green - Voltage range violation;
- Dark green - Pre- to post-contingency voltage drop violation;
- Tile - Flowgate violation;
- Red - Voltage stability violation;
- Black - User-specified transfer limit is reached but no violations are identified;
- Gray - All available generation (load) in source/sink subsystems has been used.

The limiting condition for these two simultaneous transfers is voltage constraint (dark green color). The size of the secure operating region for the base case conditions is 0.425 p.u. The size of the operating region area is normalized by x-and y-axes maximum values.

The region within the boundary is secure operating region for Transfers 1 and 2. Operating beyond the boundary is insecure (i.e., causes violation of monitored constraints).

III. Performing Contingency Analysis and Ranking Contingencies

This Section summarizes contingency analysis results while simulating Transfers 1 and 2.

The objective of the study is to determine the most severe contingencies, i.e. the contingencies that have the most limiting effect on Transfers 1 and 2.

The approach is based on the size of the area of each operating region. The area of the operating region is computed and severity of contingencies is based on the size of the operating region area.

Contingency analysis was performed while simultaneously simulating the above power transfers. Contingency list consists of 14 contingencies:

- Eight N-1 contingencies (Operations 1-7, 9)
- Four N-2 contingencies (Operations 8, 10-12)
- Two N-3 contingencies (Operations 13, 14)

Boundaries of operating region for the applied contingencies are shown in Fig. 4 and Fig. 5.

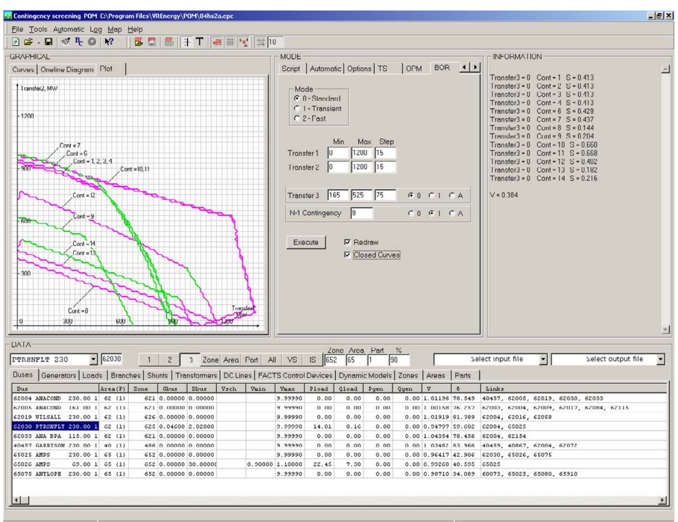

Fig. 4. Contingency Analysis While Simulating Two Transfers

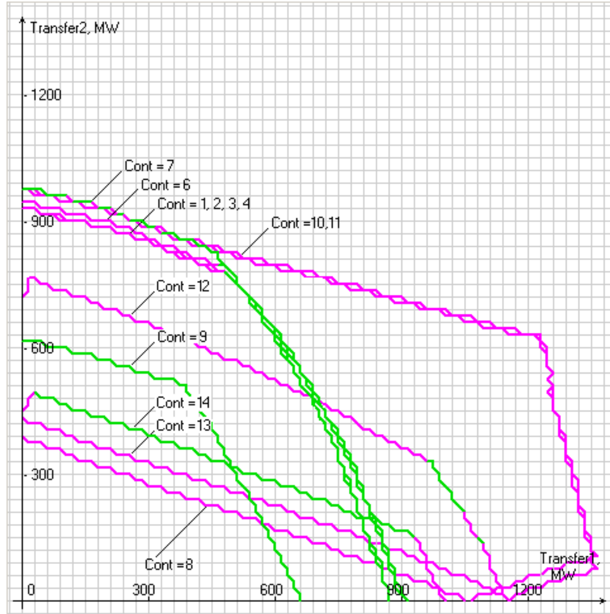

Fig. 5. Boundaries of Operating Region for All Contingencies

Operations 1 – 7 and Operation 9 are N-1 contingencies, and 5% pre- to post-contingency voltage drop is monitored as the limit. The limiting constraints for Operations 1-7 are voltage (green color) and thermal (pink color) constraints. The limiting constraint for Operation 9 is voltage (green color) constraint.

Operation 8 and Operations 10-14 are N-2 and N-3 contingencies, and 10% pre- to post-contingency voltage drop is monitored as the limit. The limiting constraints for Operations 12 and 14 are voltage (green color) and thermal (pink color) constraints. The limiting constraint for Operations 8, 10, 11 and 13 is thermal (pink color) constraint.

Operation 5 is critical on the base case level and all transfer levels. This means that Transfers 1 and 2 cannot be increased without violation of monitored constraints for this contingency. Boundary of operating region for this contingency is not drawn, and operating region area associated with this contingency is not available. This is the most limiting contingency.

Areas of secure operating regions for each of 14 contingencies are summarized in Table 1.

Table 1. Summary of Operating Region Areas (in p.u.) for Each Contingency

	Contin-gency	S (5%), p.u.	S (10% p.u.	Rank
N-1	1	0.413		4
	2	0.413		4
	3	0.413		4
	4	0.413		4
	5	-		1
	6	0.429		4
	7	0.437		4
	9	0.204		3
N-2 and N-3	8	0.144	2	
	10	0.660	5	
	11	0.668	5	
	12	0.402	4	
	13	0.182	2	
	14	0.216	3	

The most severe contingency is Operation 5, followed by Operations 8 and 13.

The smallest size of the secure region of operation that is formed by several contingencies is also determined. The boundaries that are closest to the initial point (0, 0) are boundaries for Operations 8 and 9 (see Fig. 5). This smallest area where operation is secure is the intersection of areas formed by Operations 8 and 9: it is bound by Operation 8 on the top and by Operation 9 on the right.

IV. Using Remedial Actions to Increase the Size of Secure Operating Region

This Section describes the use of remedial actions in order to increase the size of the secure operating region for each contingency.

Load curtailment was selected to increase the region after contingencies 1 – 14 have been applied.

Operating region boundaries after mitigation measure are applied are shown in Fig. 6 and Fig. 7.

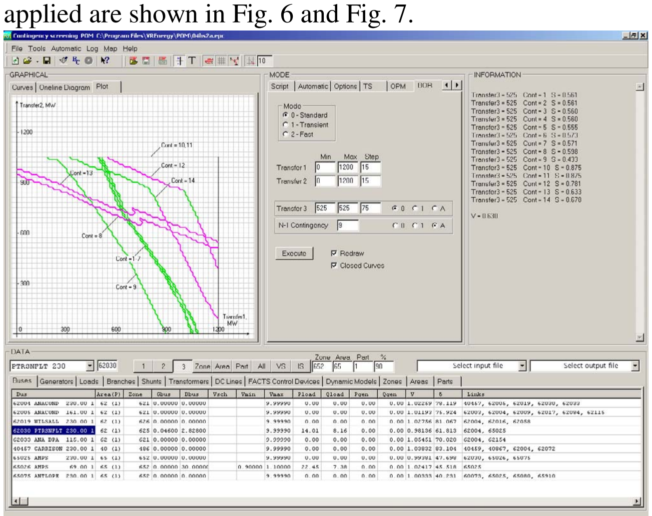

Fig. 6. Contingency Analysis and Applying Remedial Actions While Simulating Two Transfers

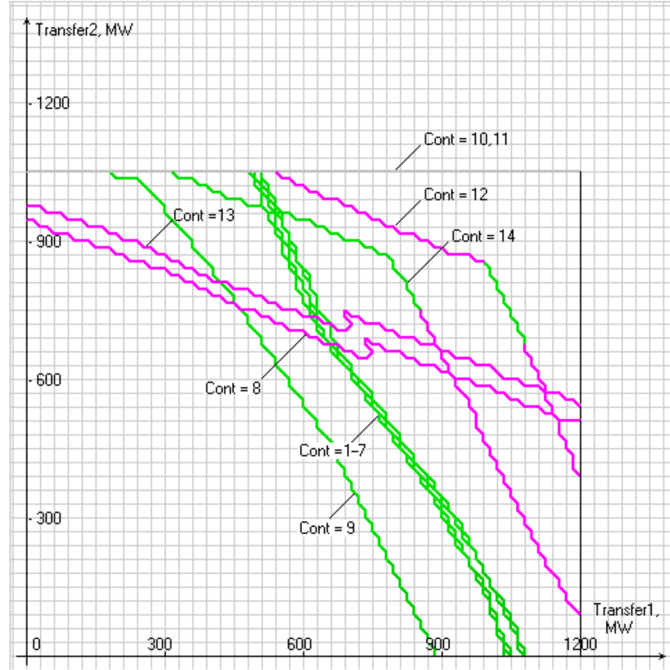

Fig. 7. Boundaries of Operating Region for Contingencies: Mitigation Measures Applied

Applying mitigation measures significantly increased the secure operating region for each contingency as compared to Fig. 5.

If mitigation measures are not applied, secure operating region for Operation 5 does not exist. After applying mitigation measures, the operating region exists, and its area is increased to 0.555 p.u.

Areas of secure operating regions for each of 14 contingencies after mitigation measures have been applied are summarized in Table 2.

Table 2. Summary of Operating Region Areas (in p.u.) for Each Contingency: Mitigation Measures Applied

	Contin-gency	S, p.u. no RAS	S, p.u. with RAS	Rank With RAS
N-1	1	0.413	0.561	2
	2	0.413	0.561	2
	3	0.413	0.560	2
	4	0.413	0.560	2
	5	-	0.555	2
	6	0.429	0.573	2
	7	0.437	0.571	2
	9	0.204	0.433	1
N-2 and N-3	8	0.144	0.598	2
	10	0.660	0.958	5
	11	0.668	0.958	5
	12	0.402	0.781	4
	13	0.182	0.633	3
	14	0.216	0.678	3

The most severe contingency after mitigation measures are applied is Operation 9.

The smallest size of the secure region of operation that is formed by several contingencies is also determined. The boundaries that are closest to the initial point (0, 0) are boundaries for Operations 8 and 9 (see Fig. 7). This smallest area where operation is secure is the intersection of the areas formed by Operations 8 and 9: it is bound by Operation 8 on the top and by Operation 9 on the right as shown in Fig. 8.

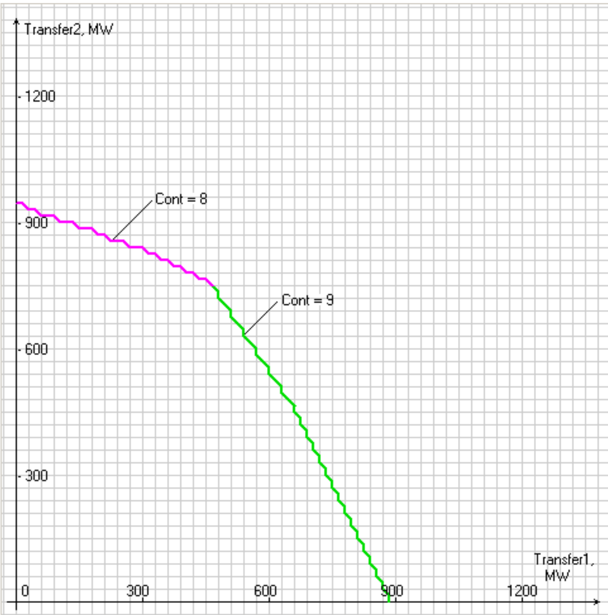

Fig. 8. The Smallest Area for Operations 1-14: Mitigation Measures Applied

V. Performing Detailed Security Analysis

A more detailed security analysis was further performed for Operation 5.

Operation 5 is the most severe contingency (prior to mitigation measures being used). The size of the operating region for this contingency has significantly increased after the mitigation measures were applied (see Fig. 7).

The study included determining the dependence of the amount of load curtailment on the size of the operating region.

Fig. 9 shows a set of operating regions for Operation 5 for different values of load curtailment. The amount of load curtailment is changed from 105 MW to 125 MW. If load curtailment is below 105 MW, the operating region does not exist for this contingency.

Fig. 9. Dependence of the Size of the Operating Region on the Amount of Load Curtailment (from 105 MW to 125 MW)

Fig. 9 illustrates the increase of the operating region with the increase of the amount of load curtailment.

Operating region boundaries for this analysis were constructed as follows:

- The amount of load curtailment is used as a parameter for a set of projections on the plane (Transfer 1, Transfer 2).
- The amount of load is increased from 105 MW to 125 MW as shown in Fig. 9.

The same concept is also illustrated in Fig. 10. In Fig. 10, the amount of load curtailment is varied from 105 MW to 525 MW (maximum available load at identified buses).

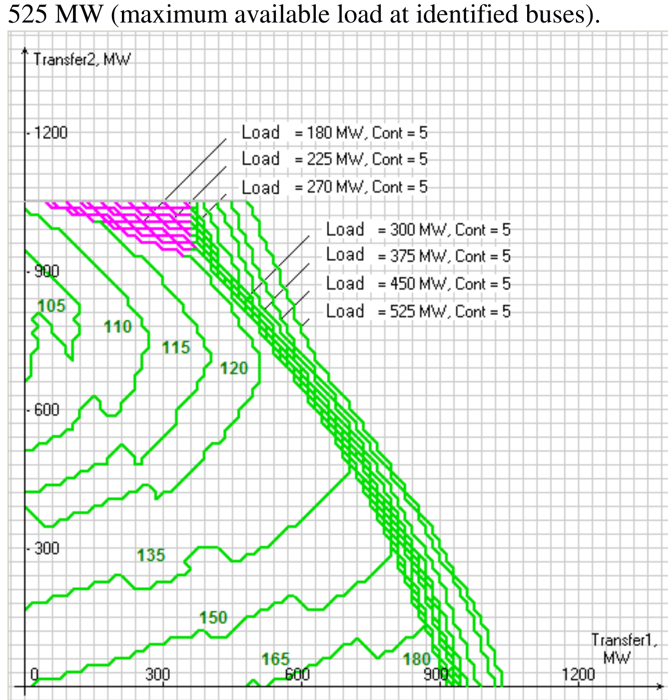

Fig. 10. Dependence of the Size of the Operating Region on the Amount of Load Curtailment (from 105 MW to 525 MW)

In Fig. 10, results are shown in 2-dimensional form as a set of projections on the plane (Transfer 1, Transfer 2) with the amount of load curtailment used as the parameter. The same results may be shown in 3-dimensional form, see Fig. 11.

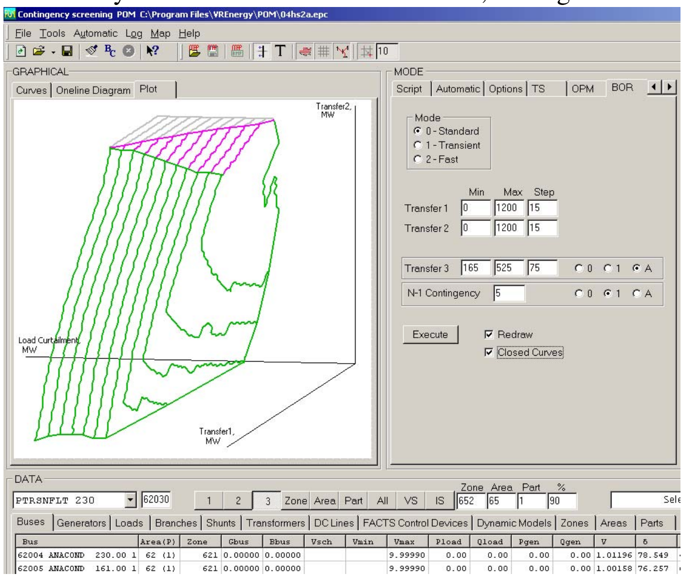

Fig. 11. Dependence of the Size of the Operating Region on the Amount of Load Curtailment in 3-Dimensional Form

The axes in Fig. 11 are:

- The x-axis represents Transfer 1
- The y-axis represents Transfer 2
- The z-axis represents the amount of load curtailment

Fig. 11 shows how the size of the secure operating region increases with the increase of the amount of load curtailment.

VI. Conclusion

This paper describes computation and plotting of the secure region of power system operation while simulating two simultaneous power transfers and performing contingency analysis in Idaho Power Co. Voltage, thermal and voltage stability limits are monitored during security analysis. Contingencies are ranked based on the size of the operating region area. The most limiting contingencies are identified.

The effect of applying mitigation measures on increasing the size of the secure operating region is analyzed.

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